

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Semiannual Progress Report
March-August, 1978



on that portion of research work performed under

NASA Research Grant NGL 04-001-007
Ames Research Center
Moffett Field, California 94035

entitled

NEPHELOMETER EVALUATION FOR MEASUREMENT OF
CLOUD PARAMETERS IN EARTH AND PLANETARY ATMOSPHERES

submitted by

Department of Electronics and Instrumentation
University of Arkansas Graduate Institute of Technology
P.O. Box 3017, Little Rock, Arkansas 72203

G. S. Ballard, Co-Principal Investigator
Assistant Professor, Electronics and
Instrumentation

MAR 20 1979

Date

M. K. Testerman, Principal Investigator
Head, Electronics and Instrumentation

(NASA-CR-158156) NEPHELOMETER EVALUATION
FOR MEASUREMENT OF CLOUD PARAMETERS IN EARTH
AND PLANETARY ATMOSPHERES Semiannual
Progress Report, Mar. 1978 - Aug. 1978
(Arkansas Univ.) 28 p HC A03/MF A01

N79-19333

Unclas
G3/36 16338

TABLE OF CONTENTS

LIST OF FIGURES	iii
LIST OF TABLES	iv
I. INTRODUCTION	1
II. WORK PERFORMED	2
A. Degree of Collimation of a He-Ne Laser Beam	2
B. Preparation and Measurement of "Standard Scatterers"	4
C. Use of GaAs Source	8
D. Using a Ring Detector and a Single Stationary Lens	8
E. Scattering Measurements Using Axicons	11
F. Summary, Observations	20
III. WORK TO BE PERFORMED	21
FIGURES	22

LIST OF FIGURES

1. Optical arrangement for measuring light intensity at angles relative to the incident beam. 22
2. Using a ring detector and a stationary lens to examine the scattering from polystyrene latex spheres. 23
3. Optical arrangement for measuring scattered light using axicons. 24

LIST OF TABLES

I. Initial Intensity Data	3
II. Intensity Data Obtained After System Adjustment	4
III. Approximation of Number of Spheres for One Slide	6
IV. Scattering from Slides with Approximate Number of Spheres Determined	7
V. Ring-Detector Readings for a Representative Slide	10
VI. Comparison of Readings from Five Slides	11
VII. Typical Determination of Particle Count for One Slide	13
VIII. Number of Particles Determined for Each Slide	13
IX. Measurements with 4-Degree Reflecting Axicon	14
X. Measurements with 9-Degree Reflecting Axicon	16
XI. Measurements with 19-Degree Reflecting Axicon	17
XII. Measurements with 49-Degree Reflecting Axicon	18
XIII. Measurements with 5-Degree Refracting Axicon	19

**Semiannual Progress Report
March-August, 1978**

**on research work performed under
NASA Grant No. NGL 04-001-007**

on

**NEPHELOMETER EVALUATION FOR MEASUREMENT OF
CLOUD PARAMETERS IN EARTH AND PLANETARY ATMOSPHERES**

by

G. S. Ballard and M. K. Testerman

**Department of Electronics and Instrumentation
University of Arkansas Graduate Institute of Technology
P.O. Box 3017, Little Rock, Arkansas 72203**

I. INTRODUCTION

During the first six months of work under this portion of NASA Grant No. NGL 04-001-007, progress was made in several areas related to nephelometer evaluation. Initial work was concerned with determining whether the radiation emitted from a laser source could be sufficiently collimated to provide a suitable source for a nephelometer-type instrument. Next, it was necessary to develop a "standard scatterer" that could be used to evaluate the performance of a nephelometer. The possible use of a gallium arsenide diode as a radiation source also was investigated. Finally, two possible nephelometer configurations were investigated. The first of these utilized a single lens to focus the light scattered from a target onto a ring detector. The second configuration used reflecting and refracting axicons as optical-system elements. The work performed in each

of these areas is described in the following sections of this paper. Work remaining to be performed also is noted briefly.

II. WORK PERFORMED

A. Degree of Collimation of a He-Ne Laser Beam

The apparatus used for measuring light intensity at various angles relative to an incident beam of parallel light is shown in Figure 1. The laser was located in a room in which the beam was expanded and collimated. The collimated beam then was passed through an aperture in the wall and into a dark room where the detector was located. A focusing lens, a pinhole, and the detector were located as a unit upon an arm that rotated about the primary beam. The dimensions of the system were as follows:

Pinhole to limiting aperture	15.5 cm
Pinhole to collimating lens.	25.0 cm
Collimating lens to first iris	32.5 cm
First iris to second iris.	33.0 cm
Second iris to center of rotation.	12.5 cm
Center of rotation to aperture and focusing lens . .	34.0 cm
Focusing lens to pinhole	17.5 cm
Beam diameter.	1.0 cm
Diameter of measuring aperture	1.25 cm
Angular resolution	<u>+0.25°</u>

A number of these dimensions are quite arbitrary, determined only by convenience during the initial set-up and alignment of the instrument. They are presented only to give an idea of the physical size of the system.

Initial data obtained with this system are shown in Table I. Relative intensity measurements are those obtained directly from the moveable detector and normalized with respect to the intensity along the optical axis. These intensity measurements represent only a portion of the light

surrounding the incident beam at any given angle, and they should be corrected to include all of the radiation about the axis. The area of the collecting optics is

$$A_1 = \pi R^2, \quad (1)$$

where R is the radius of the collecting aperture. If this aperture were moved around the optical axis in a circle to gather all of the light at a given angle, it would describe an annulus of area

$$A_2 = \pi(r_2^2 - r_1^2), \quad (2)$$

where r_1 and r_2 are the distances from the optical axis to the inner and outer edges, respectively, of the collecting aperture. The measured relative intensity measurements should, therefore, be multiplied by the correction factor A_2/A_1 to compare the total radiation found at various angles. Correction factors for the system configuration and corrected intensities are listed in Table I.

TABLE I

Initial Intensity Data

Angle (degrees)	Relative Intensity	A_2/A_1	Corrected Intensity
0	1.0×10^0	1.00	1.00×10^0
1	9.6×10^{-5}	3.74	3.59×10^{-4}
2	3.0×10^{-7}	7.47	2.24×10^{-6}
3	2.0×10^{-8}	11.21	2.24×10^{-7}
4	1.7×10^{-8}	14.94	2.54×10^{-7}

At angles greater than 4 degrees, the measured light intensities began to increase with angle. This was found to result from radiation scattered from the collimating-lens mount and other system components. An attempt was made to eliminate this noise, and the system was carefully re-aligned and adjusted. The data presented in Table II were then obtained. These data show that the corrected intensity at 2 degrees is down by slightly more than six orders of magnitude from that measured on the optical axis.

TABLE II

Intensity Data Obtained After
System Adjustment

Angle (degrees)	Relative Intensity	Corrected Intensity
0	1.00×10^0	1.00×10^0
1	1.88×10^{-4}	7.03×10^{-4}
2	1.28×10^{-7}	9.56×10^{-7}
3	3.52×10^{-8}	3.95×10^{-7}
4	1.36×10^{-8}	2.03×10^{-7}
5	7.20×10^{-9}	1.34×10^{-7}
6	3.36×10^{-9}	7.52×10^{-8}
7	1.84×10^{-9}	4.80×10^{-8}

B. Preparation and Measurement of "Standard Scatterers"

"Standard scatterers" were prepared by depositing polystyrene latex spheres on the surface of clean microscope slides. These spheres are uniform in diameter and produce a well-defined diffraction pattern.

An electrostatic precipitator was used to coat the slides. The number of spheres deposited was roughly proportional to the time that precipitation was allowed to take place, so there was some degree of control over particle density. Small spheres adhere quite well to the glass slides, but those with diameters larger than $2\text{ }\mu\text{m}$ tend to drop off as the slides are handled. Slides were prepared using spheres with diameters of either $2.02\text{ }\mu\text{m}$ or $1.01\text{ }\mu\text{m}$. Several prepared slides were placed in the collimated laser beam at the center of rotation (Figure 1), and their diffraction patterns were obtained. The $2.02\text{-}\mu\text{m}$ spheres showed a maximum in their diffraction pattern at approximately 25 degrees. For the $1.01\text{-}\mu\text{m}$ spheres, the maximum was found at approximately 37 degrees.

If the spectrum of the spheres alone is to be determined, the background contributed by the glass of the slide should be subtracted from the coated-slide measurement. It was found that this background varied significantly from one clean slide to another and varied within different portions of the same slide. In later work, the background of each slide was obtained before coating, and provisions were made for placing the slide in the laser beam in a repeatable manner.

For quantitative measurements, it is necessary to determine the number of spheres illuminated by the laser and contributing to the scattering signal. This number can be estimated by using a microscope to count the spheres on a portion of the slide. Several such counts, all made within the area of the slide to be illuminated with the laser, will give the approximate number of spheres per unit area deposited on a given slide. A typical determination of the approximate number of spheres illuminated on one particular slide is illustrated in Table III.

TABLE III

Approximation of Number of Spheres for One Slide

Microscope Observation	Spheres Counted
1	13
2	9
3	14
4	9
5	9
Average Spheres	10.8
Microscope Field of View Area	0.0015 cm ²
Area of Laser Illumination	0.2 cm ²
Number of Spheres Illuminated = (10.8)(0.2)/0.0015	
= 1440	

Eight slides were prepared using 2.02- μ m-diameter polystyrene latex spheres. The number of spheres illuminated on each slide was determined, and the scattering from each slide was measured at an angle of 25 degrees, or at the maximum intensity of the first bright ring of the particle diffraction pattern. The data from these slides are presented in Table IV.

TABLE IV

Scattering from Slides with
Approximate Number of Spheres Determined

Slide	Approximate Number of Particles N	Signal I at 25° Angle (A)
A	1440	1.73×10^{-8}
B	1870	2.35×10^{-8}
C	5660	3.10×10^{-8}
D	5970	3.40×10^{-8}
E	6530	3.10×10^{-8}
F	7760	4.95×10^{-8}
G	6190	3.10×10^{-8}
H	7090	3.85×10^{-8}

The straight line formed by these points was found using the least-squares method. The equation for this line is

$$I_{(A)} = 3.6 \times 10^{-12}N + 1.29 \times 10^{-8}$$

with a correlation coefficient of 0.88. The I intercept ($N = 0$) of 1.29×10^{-8} is close to the scattering observed from clean microscope slides at this angle.

The results of this experiment indicated that microscope slides coated with polystyrene latex spheres could be used as "standard scatterers" to help determine the performance of various nephelometer configurations. It was found that extreme care would be required in cleaning and coating the slides, that more particle counts would be necessary for a better statistical determination of the number of particles illuminated, and that

great care must be exercised in the placement of the slides in the illuminating radiation.

C. Use of GaAs Source

This portion of the work employed the same general experimental set-up as was used in the work described in Section B, except that a Texas Instruments TIXL16 gallium arsenide diode was the radiation source and a United Detector Technology PIN-5D photodiode was the detector. This arrangement was used to attempt to measure the scattering spectrum of 2.02- μ m spheres. With these substitutions it was not possible to measure the scattering from samples at angles exceeding 10 degrees. Reference to Table II shows that the signals expected are approximately seven orders of magnitude below that for the incident radiation. Either a more powerful source of radiation, a more sensitive detector, or a combination of the two would be necessary to observe the scattering at large angles.

D. Using a Ring Detector and a Single Stationary Lens

A ring detector and a lens were set up as shown in Figure 2 to examine the scattering spectra of polystyrene latex spheres. The detector was a Recognition Systems, Inc., Diffraction Pattern Sampling Unit (DPSU) Model WR D 6420A. The DPSU has 64 P-on-N silicon photodiodes. It is divided into two sampling regions, one consisting of 32 angular rings, the other of 32 wedges. Only the rings were used for these measurements. Except for a center circle of 0.1-mm radius, the remaining 31 rings are annular "half-rings" varying in radius from 0.24 to 15.9 mm.

It was found necessary to block the incident laser beam before it reached the transform lens, otherwise scattered and reflected radiation gave a very high background signal, much larger than the scattering signals. Even with the D-C stop in place, there was still a rather high background. It is believed that this contributed to the rather poor results obtained in this experiment.

With a 10.2-cm-focal-length lens and an outer ring radius of only 15.9 mm, the maximum angle of scattering that could be measured was approximately 8.5 degrees. Using a Fresnel lens 2.5 cm in diameter and having a focal length of 1.5 cm allowed light scattered at angles up to 40 degrees to be measured. One drawback to using a lens with such a short focal length is that the experimental set-up is very cramped. Also, the D-C stop used to block the laser radiation effectively screens some of the smaller-radii rings. Use of a larger-radius ring detector would permit the use of a lens with a longer focal length to obtain a desired angular resolution, resulting in a more flexible and less noisy optical arrangement.

Five slides were prepared using 2.02- μ m spheres. First, each of the clean slides was placed in the laser beam, and the scattering from the glass alone was measured. Next, the spheres were electrostatically precipitated onto the slides, and their scattering spectrum was measured. Finally, each slide was placed under the microscope, and the particles were counted as described in Section B. The readings for a representative slide are given in Table V. Rings 1 through 16 were not read, as they were masked by the D-C stop. The largest reading was found on ring number 22, which corresponds to an angle of approximately 25 degrees.

TABLE V
Ring-Detector Readings for a
Representative Slide (Slide Number 1)

Ring Number	Coated-Slide Signal (mV)	Clean-Slide Signal (mV)	Spheres Alone (mV)
17	0.21	0.18	0.03
18	0.32	0.26	0.06
19	0.49	0.39	0.10
20	0.69	0.56	0.13
21	0.68	0.49	0.19
22	0.55	0.29	0.26
23	0.13	0.10	0.03
24	0.15	0.11	0.04
25	0.17	0.13	0.04
26	0.20	0.15	0.05
27	0.23	0.18	0.05
28	0.26	0.22	0.04
29	0.27	0.22	0.05
30	0.28	0.23	0.05
31	0.30	0.26	0.04
32	0.48	0.40	0.08

The signal from the maximum reading (ring 22) was compared with the number of particles illuminated, as estimated from the microscope count, for each of five slides (see Table VI). There is not a great deal of agreement between particle count and scattering intensity, the correlation coefficient for the five points being only 0.6. Several factors may have contributed to this result. For one, the spheres were not uniformly distributed on the slides; there was a large variation in the number of spheres counted on different areas of a given slide, which could make the count determination inaccurate. Also, it was noted that a great deal of material which appeared

to be glass particles, or other foreign matter, was present after precipitation. This suggests that the solution containing the spheres was contaminated or that the air used to form the aerosol prior to precipitation was not properly filtered. Finally, the close working distances necessary when using the 1.5-cm-focal-length lens may have introduced some errors.

TABLE VI

Comparison of Readings from Five Slides

Slide Number	Spheres Signal (Ring 22) (mV)	Number of Particles
1	0.26	1250
2	0.13	1335
3	0.17	1600
4	0.20	1200
5	0.07	385

E. Scattering Measurements Using Axicons

Several axicons were obtained from NASA-Ames Research Center for these experiments. Four of these were reflecting axicons that were found to reflect parallel light at angles of 4, 9, 19, and 49 degrees. One axicon was made of a transparent material and was found to refract parallel light at an angle of 5 degrees. These axicons were used with particle-coated microscope slides in an attempt to determine the performance of a nephelometer that utilizes axicons to measure the intensity of radiation scattered at several discrete angles. Figure 3 shows the optical arrangement for these experiments.

Six slides were coated with 2.02- μ m-diameter polystyrene latex spheres. After the scattering measurements had been made, the number of spheres illuminated by the laser were estimated by the microscope method described in Section B of this report. The microscope was used to count the number of particles at nine different points on the slide, all of the points being within the region of the slide illuminated during the scattering measurements. A typical determination of the particle count for one slide is listed in Table VII. The number of particles determined for each of the six test slides is shown in Table VIII.

A set of measurements was made using the 4-degree reflecting axicon. This axicon was positioned as shown in Figure 3 and was carefully aligned. Each of the six clean microscope slides was placed in the laser beam, and the scattering from the glass alone was measured. These data are listed in Table IX under the clean-slide heading. Next, 2.02- μ m-diameter polystyrene latex spheres were deposited upon the slides, using the electrostatic precipitator. Each coated slide was then replaced in the optical system, and the coated-slide measurements of Table IX were made. A measurement was also made with no slide present in the beam; this reading represents the light scattered by the optical-system components.

TABLE VI'

Typical Determination of Particle Count
for One Slide

Microscope Observation	Spheres Counted
1	7
2	7
3	8
4	9
5	10
6	10
7	8
8	10
9	7
Average Spheres	8.4
Standard Deviation	1.3
Microscope Field of View Area	0.0015 cm ²
Area of Laser Illumination	0.049 cm ²
Number of Spheres Illuminated = (8.4)(0.049)/0.0015	
= 276	

TABLE VII

Number of Particles Determined
for Each Slide

Slide Number	Average Spheres per Observation	Standard Deviation	Particles Illuminated
1	8.4	1.3	276
2	9.8	4.0	302
3	28.3	5.3	927
4	28.8	3.4	942
5	54.2	14.4	1774
6	54.9	7.2	1796

TABLE IX

Measurements with 4-Degree
Reflecting Axicon (Forward Scattering)
(No Slide in Beam: $I = 0.43 \mu A$)

Slide Number	Coated (μA)	Clean (μA)	Difference (μA)
1	16.3	8.1	8.2
2	21.9	12.5	9.4
3	34.0	16.0	18.0
4	36.0	21.5	14.5
5	46.5	15.4	31.1
6	43.0	18.7	24.3

The numbers in the difference column were obtained by subtracting the clean-slide reading from that obtained with the coated slide. These numbers, which are assumed to represent the signal arising from the spheres themselves, were combined with the appropriate particle counts from Table VIII, and the equation for the straight line described by these points was obtained using the method of least squares. The equation for the line was found to be

$$I_{(\mu A)} = 0.013N + 4.774.$$

The correlation coefficient was 0.958. Thus, each sphere contributed a signal of approximately $0.013 \mu A$ to the total scattering signal. The noise contributed by scattering from the optical system ($0.43 \mu A$) was read on the 10^{-6} scale. If it is assumed that the smallest detectable signal is one division on this scale, then a signal as small as $10^{-8} A$ could be detected.

This is slightly smaller than the signal obtained from a single sphere, indicating that the scattering from one 2.02- μ m-diameter sphere could be detected with the optical system used in these experiments.

A source of scattering was located after these experiments were performed, and indications were that the elimination of this background would have reduced the background for the measurements made with the 4-degree axicon by one order of magnitude, making the signal-to-noise calculations even more favorable for single-particle detection.

The method of least squares was also applied to the coated-slide measurements from Table IX. The equation obtained from these points was

$$I_{(\mu A)} = 0.017N + 15.88.$$

The correlation coefficient was 0.961. This indicated a slightly larger signal contribution from each sphere than that obtained with the difference data, but the two are in fairly close agreement. It was interesting to note that the above line would intercept the current axis at a value of 15.9 μ A. This is remarkably close to the average clean-slide measurement from Table IX, which was 15.3 μ A.

A similar procedure was followed for the other three reflecting axicons using the same six coated slides. The measurements obtained with the 9-degree axicon are shown in Table X. The data for the 19-degree axicon are contained in Table XI, and the data for the 49-degree axicon are in Table XII.

TABLE X

Measurements with 9-Degree Reflecting
Axicon (Forward Scattering)
(No Slide in Beam: $I = 0.09 \mu A$)

Slide Number	Coated (μA)	Clean (μA)	Difference (μA)
1	0.83	0.57	0.26
2	0.92	0.52	0.40
3	1.72	0.86	0.86
4	1.83	0.94	0.89
5	2.59	0.71	1.88
6	2.38	0.94	1.44
	Average	0.76	

Using the difference data from Table X:

$$I_{(\mu A)} = 0.0009N + 0.056.$$

The correlation coefficient was 0.970. Using the coated-slide data from Table X:

$$I_{(\mu A)} = 0.0011N + 0.637$$

The correlation coefficient was 0.983. With a background of $0.09 \mu A$, either of these equations indicates that the signal from a single sphere could just be detected with the system used.

TABLE XI

Measurements with 19-Degree Reflecting
Axicon (Forward Scattering)
(No Slide in Beam: $I = 0.027 \mu A$)

Slide Number	Coated (μA)	Clean (μA)	Difference (μA)
1	1.03	0.565	0.465
2	1.01	0.470	0.540
3	1.32	0.525	0.795
4	1.35	0.720	0.630
5	1.80	0.540	1.260
6	1.56	0.655	0.905
		Average 0.579	

Using the difference data from Table XI:

$$I_{(\mu A)} = 0.0004N + 0.373.$$

The correlation coefficient was 0.895. Using the coated-slide data from Table XI:

$$I_{(\mu A)} = 0.0004N + 0.902.$$

The correlation coefficient was 0.963. With a background of $0.027 \mu A$, these equations indicate that approximately three $2.02\text{-}\mu\text{m}$ -diameter spheres would be necessary to produce a detectable signal.

TABLE XII

Measurements with 49-Degree Reflecting
Axicon (Forward Scattering)
(No Slide in Beam: $I = 0.015 \mu A$)

Slide Number	Coated (μA)	Clean (μA)	Difference (μA)
1	0.750	0.525	0.180
2	0.690	0.570	0.110
3	0.840	0.341	0.499
4	0.935	0.420	0.515
5	0.960	0.250	0.710
6	1.250	0.380	0.870
	Average	0.414	

From the difference data of Table XII:

$$I_{(\mu A)} = 0.0004N + 0.050.$$

The correlation coefficient was 0.971. Using the coated-slide figures from Table XII:

$$I_{(\mu A)} = 0.0003N + 0.614.$$

The correlation coefficient was 0.890. The minimum detectable signal for this background level would be $0.001 \mu A$. Four spheres would be required to produce this signal.

For backward-scattering measurements, the 5-degree refracting axicon was placed in the optical system in the position indicated in Figure 3, and the same procedure was followed as was used for the previous measurements. The data obtained are listed in Table XIII.

TABLE XIII

Measurements with 5-Degree Refracting Axicon
(Backward Scattering)
(No Slide in Beam: $I = 0.020 \mu A$)

Slide Number	Coated (μA)	Clean (μA)	Difference (μA)
1	0.96	0.82	0.14
2	1.29	1.13	0.16
3	2.20	1.27	0.93
4	3.41	1.33	2.08
5	3.56	1.06	2.50
6	2.50	<u>1.11</u>	1.39
	Average	1.12	

For the backward-scattering measurement, the difference figures in Table XIII give:

$$I(\mu A) = 0.0012N + 0.02.$$

The correlation coefficient was 0.797. The coated slide measurements in Table XIII give:

$$I(\mu A) = 0.0012N + 1.08.$$

The correlation coefficient was 0.768. With a minimum detectable signal of 0.001 μ A, a single sphere should be seen.

F. Summary of Observations

It appears that a laser would be a suitable radiation source for a nephelometer. It has been demonstrated that the light intensity measured at an angle of 2 degrees from the axis of a well-collimated He-Ne laser beam is six orders of magnitude less than the intensity of the beam as measured directly on the axis.

Microscope slides coated with polystyrene latex spheres can be used to determine the performance of various nephelometer configurations. Extreme care must be taken in positioning the slides for scattering measurements. Measurements obtained with individual slides can vary greatly, depending upon which portion of the slide is illuminated and also upon the orientation of the slide with respect to the illuminating radiation.

The particular combination of a gallium arsenide diode emitter and a photodiode detector used for part of this study was not suitable for the types of measurements that were attempted. Much of the radiation emitted by the source was lost in attempting to collimate the beam to the high degree required. Scattering signals at large angles were too weak to measure.

A ring detector positioned at the back focal plane of a stationary lens could be a useful nephelometer configuration. The system should be designed with a large numerical aperture so that light scattered at large angles could be measured. It would be helpful if both the lens and the detector were constructed with orifices in their centers that would allow the incident radiation to pass through them without scattering. The D-C stop used in these measurements to block this radiation was not completely effective, and a high background signal was the result.

Axicons appear to be practical components in a nephelometer design. With the system described in this report, it has been estimated that the scattering from single 2- μ m-diameter particles can be detected at angles though 9 degrees. At 49 degrees, approximately four of these particles would produce a detectable signal.

III. WORK TO BE PERFORMED

During the second half of this 12-month grant period, measurements similar to those described in Section E of this report will be obtained using 1.01- μ m-diameter polystyrene latex spheres. Like the 2.02- μ m spheres, these are almost perfect spheres, and they can be deposited on microscope slides using the electrostatic precipitator.

Larger spherical particles, such as pollen grains, will also be studied. Nearly spherical pollens with diameters in the 15- μ m range are readily available. Some method other than electrostatic precipitation will be used to deposit these large particles upon microscope slides.

If they become available, nonspherical particles will also be studied during the next six months.

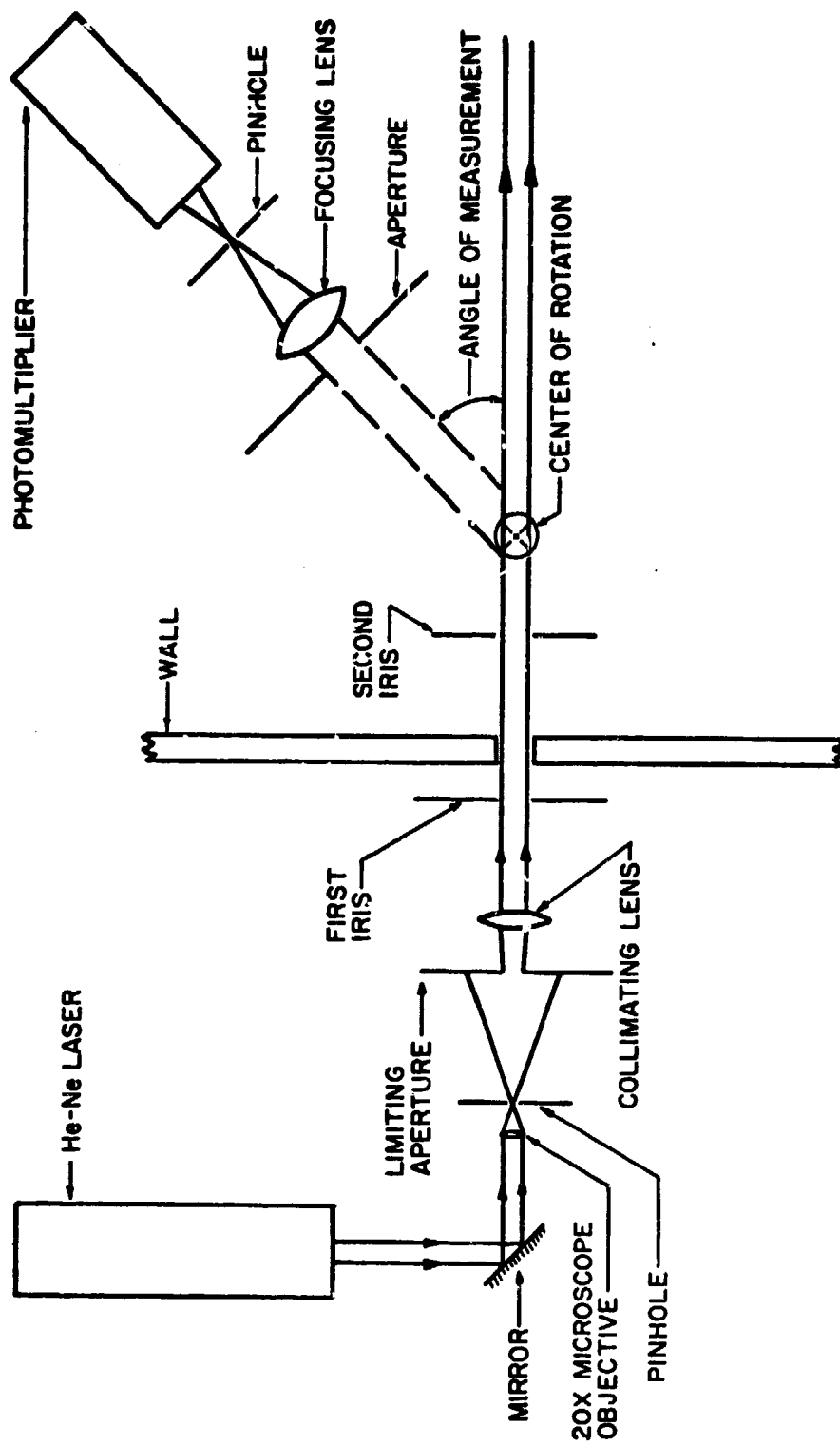


Fig. 1. Optical arrangement for measuring light intensity at angles relative to the incident beam.

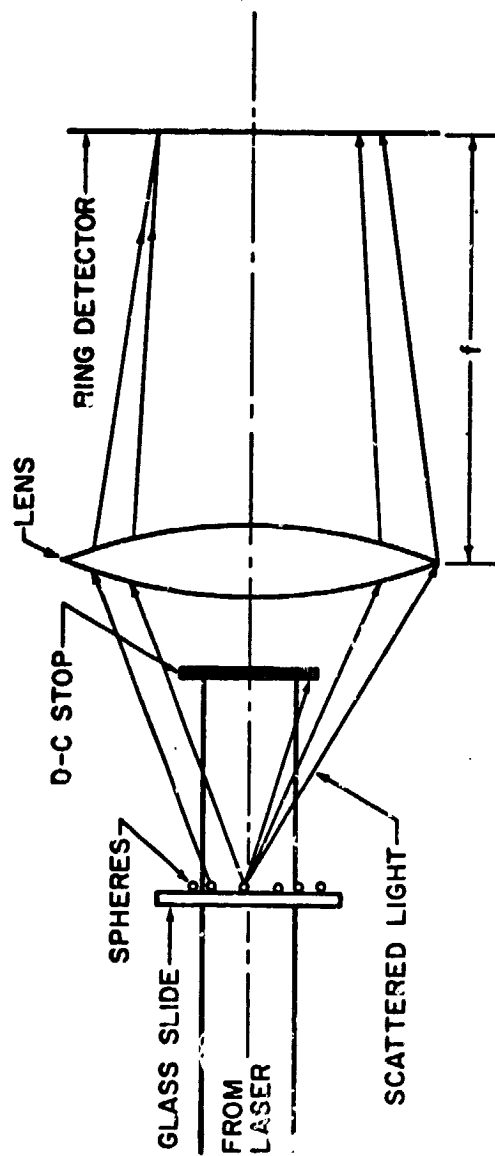


Fig. 2. Using a ring detector and a stationary lens to examine the scattering from polystyrene latex spheres.

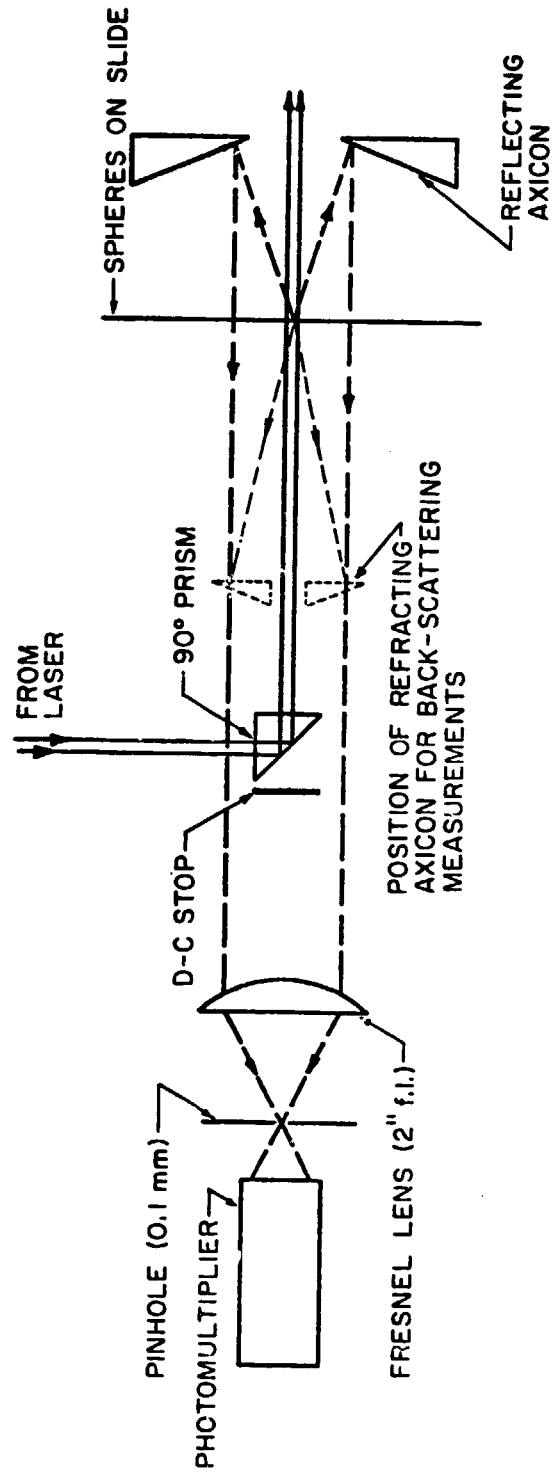


Fig. 3. Optical arrangement for measuring scattered light using axicons.